(54) Title: REACTOR FOR PLASMA TREATMENT OF GASES
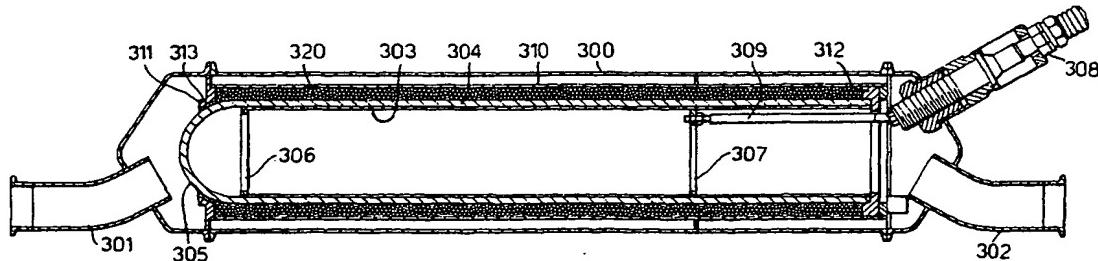
(57) Abstract: In a non-thermal plasma reactor (300), at least a component of the active material (320) is selected or modified to provide the capability to adsorb or trap a predetermined chemical species in the gas flow thereby to increase the effective residence time of said species relative to the residence time of unadsorbed species in the gas flow.

Reactor for Plasma Treatment of Gases

The invention relates to a reactor for plasma
treatment of gases and more particularly to a method of
5 manufacturing a reactor utilising a non-thermal plasma.

There is increasing interest in the use of non-
thermal plasmas for treatment of gaseous exhausts and in
particular for treatment of exhausts from motor vehicles.
10 Treatment of exhausts involves conversion of harmful
exhaust components such as hydrocarbons to carbon dioxide
and water as well as harmful NO_x components of exhausts
to nitrogen. In the case of lean burn engines such as
diesels there is a requirement for removal of
15 carbonaceous particulates by for example oxidation to
carbon dioxide. Examples of non-thermal treatment of
exhausts are described in US 3,983,021 (Monsanto), US
5,147,516 (Tecogen) and US 5,254,231 (Battelle Memorial
Institute). GB 2,274,412 (AEA Technology) describes a
20 method for the treatment of diesel emissions by a non-
thermal plasma for oxidation of carbonaceous particulates
and reduction of NO_x to nitrogen.

Plasma can be used to activate or produce reactant
25 species, which then subsequently react with or without
catalytic enhancement to yield the desirable products.
For example, our publication WO99/12638 describes the
plasma production of plasma activated hydrocarbons as a
precursor to the selective catalytic reduction of NO_x to
30 N_2. Examples of catalysts for this selective reduction of
NO_x to nitrogen are alkali metal-exchanged zeolite Y or
silver aluminate. Other metal-exchanged or metal doped

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zeolite material such as those known as Cu/ZSM-5, Fe/ZSM-
5, Co/ZSM-5, zeolite beta and hydrogen exchanged zeolites
such as H-ZSM-5 are suitable materials. Other suitable
catalysts are aluminas including alpha, gamma, chi and
5   other crystalline phases, oxides of titanium, zirconium,
cerium and vanadium, perovskites, spinels and mixtures of
these materials. Metal doped inorganic oxides such as
cobalt-doped aluminas are also suitable materials.
Examples of suitable catalysts are also described in an
10 article 'Selective catalytic reduction of NOx with N-free
reductants' by M Shelef published in Chem Rev 1995,
pp209-225.

In such catalytically enhanced plasma processes the
15 reactant species such as plasma activated hydrocarbons,
which can include oxygenated hydrocarbons, are often
produced as intermediates in e.g. the stepwise
decomposition of hydrocarbons by reactions of O_2, O, OH
and HO_2. Where the reactants are intermediates and the
20 catalyst is highly selective to a given reductant,
optimisation of the process can become difficult, if not
impossible. This is because the completeness of the
plasma reactions and hence the concentration of
intermediates is controlled largely by the input power
25 (joules per second) for a given residence time in the
plasma reactor. This leads to the idea of a normalised
unit expressed in joules per litre, which will determine
the concentration of intermediates in a plasma reactor.
For example in an article 'Plasma assisted catalytic
30 reduction of NO_x by BM Penetrante et al, SAE 982508, it
is shown how the gas phase composition changes with input
power expressed as joules per litre of gas volume for an
exhaust flow in litres per unit time. This key
parameter, joules/litre, is largely fixed by vehicle

constraints, i.e. reactor size, and the acceptable level
of power input to the reactor in as far as all of the
exhaust passes through the reactor.

5   The present invention is based upon an appreciation
of the advantages that follow if one changes the
residence time of selected species in the reactor, and
thus breaks the, at present unavoidable, link between
joules per litre input power and reactant species. This
10 would lead to a simplification in the design and an
improvement in the energy efficiency of plasma reactors.

        Examples have been given which show that, without
catalytic enhancement, plasma reactors can produce
15 quantities of undesirable by-products usually associated
with partial oxidation of hydrocarbons (see 'Analysis of
plasma-catalysis for diesel NO_x remediation' by J Hoard
and M L Balmer, SAE 982429), for example methyl nitrate,
formaldehyde. A solution is offered if hydrocarbons can
20 be retained for relatively long periods of time to
achieve complete conversion to CO and CO_2, while oxides of
nitrogen may require a short residence time to avoid
formation of acids.

25   It is an object of the present invention to provide
a method of manufacturing a component for a non-thermal
plasma reactor which addresses these problems.

        The invention provides, in one of its aspects, a
30 method of manufacturing a component for a non-thermal
plasma reactor for the treatment of gases, which method
comprises assembling a bed of active material in an

enclosure having gas flow conduits for directing gas to
flow through or over the bed of active material,
providing electrodes adapted when electrically energised
to generate non-thermal plasma in the gas, characterised
5   in that at least a component of the active material is
selected for its capability to adsorb or trap a
predetermined chemical species in the gas flow thereby to
increase the effective residence time of said species
relative to the residence time of species in the gas flow
10   which are not adsorbed or trapped.

        Preferably the said active material or component
thereof is selected for its capability to adsorb or trap
a predetermined chemical species in the exhaust gas flow
15   produced as a result of the combustion of fuel, and any
modifier or additive therein, by the internal combustion
engine.

        Or further, the said active material or component
20   thereof may be selected for its capability to adsorb or
trap a predetermined chemical species in the gas flow
produced by non-thermal plasma activation of constituents
thereof.

25   In accordance with the invention in these
circumstances the predetermined chemical species may be,
but is not restricted to a species from the group
comprising nitrogen, oxygen, oxides of nitrogen such as
NO, NO_2, oxides of carbon such as CO, CO_2, water,
30   hydrocarbons including saturated, unsaturated, cyclic,
branched and un-branched hydrocarbons, oxygenated
hydrocarbons such as aldehydes, ketones, alcohols, acids
ethers and esters, aromatic hydrocarbons and derivatives
thereof including poly aromatic hydrocarbon compounds,

oil fractions, fuel and partially burned fuel, air and
air/fuel mixes, smoke, carbonaceous particulate including
the soluble organic fraction and carbon, fine and
ultrafine fraction, sulphur compounds including SO_2 and
5   sulphates, organo-nitrogen species, acid gases,
combustion modifiers/enhancers, additives such as urea,
ammonia, cerium oxide (such as Eolys) and plasma
activated species such as O, OH, O_3 activated
hydrocarbons including partially oxygenated hydrocarbons/
10 organic molecules and electronically and vibrationally
excited state species.

The invention includes a non-thermal plasma reactor
for the treatment of gases, comprising a bed of active
15 material in an enclosure having gas flow conduits for
directing gas to flow through or over the bed of active
material, electrodes adapted when electrically energised
to generate non-thermal plasma in the gas, characterised
in that at least a component of the active material is
20 modified so as to adsorb or trap a predetermined chemical
species in the gas flow to increase the effective
residence time of the said species relative to the
residence time of species in the gas flow which are not
adsorbed or trapped. The combination of packing material
25 and the electrode spacing are chosen so as to generate
the desired plasma conditions.

The function of the active material, or component
thereof, having the capability to adsorb or trap selected
30 species can be seen as that of a selective filter for
that species.

In addition to the advantages, referred to above,

which result from the effective increase in residence
time of the selected species, such a selective filter can
operate to adsorb or trap the reactants and hold them for
sufficient time for them to be activated by a plasma
5   and/or selected filter to a state where they can react
with for example NO_x to yield desirable products. In
this role the filter material or trapped species in the
presence of a plasma can be made to appear to act as a
catalytic surface but importantly neither the plasma nor
10 the selective filter nor the trapped species alone need
have catalytic properties. One example of a trapped
species is carbonaceous particulate material from a
diesel engine, for example soot that consists mainly of
elemental carbon. In the plasma region soot becomes
15 exposed to plasma generated species for example oxygen
atoms. Oxygen atoms or other plasma generated species
may diffuse into, adsorb and react with soot. Other
plasma generated species include but are not restricted
to OH, O_3 and NO_2. For example it is known oxygen atoms
20 can diffuse into soot and form aldehyde-type groups on
the surface. Oxygenated soot has different activated and
catalytic properties to non-oxygenated soot. In this
example the surface of the reactant material, e.g. carbon
is transformed into a catalyst.

25

        A selective filter according to the present
invention provides, by selective modification of
residence times, a method of controlling and hence
optimising the distribution of product species from a
30 plasma reactor with a significant degree of independence
from flow rate, reactor size or energy density. The
method of controlling and hence optimising the
distribution of product species may include a method for
optimising the desorption of the selectively filtered

species or by-product from these species following
material or plasma activation, for example by variation
of the temperature or the filter material.

5   Following the selective filtration of carbonaceous
particulate in the plasma region the operation of the
selective filter according to the present invention also
allows for the desorption and/or decomposition by
reactive or thermal methods of the carbon functionalities
10   formed on the surface or in the bulk, such as for example
aldehyde-type groups formed on the surface. However, an
important aspect of this functioning of the selective
filter is that it provides for the carbonaceous soot to
be oxidised at low temperatures to CO_2 and CO.
15   Ordinarily, carbonaceous soot combusts at high
temperature in excess of 500°C whereas, utilising this
function of the selective filter, the soot can be
oxidised effectively at temperatures as low as 100°C.
This is a major advance over prior art soot oxidation
20   catalysts where temperatures are typically lowered to 250
- 300°C

A specific embodiment of the invention will now be
described by way of example with reference to the
25   accompanying drawings, which illustrate one suitable form
for the structure of a reactor and its bed of active
material. In the drawings:

Figure 1 is a longitudinal section of the reactor,
30   and

Figure 2 is a schematic view showing the gas flow
path through the reactor of Figure 1,
Referring to Figure 1, a reactor for the plasma

assisted processing of the exhaust emissions from
internal combustion engines to remove noxious components
therefrom consists of a reactor chamber 300 which has
inlet and outlet stubs 301, 302, respectively, by means
5   of which it can be incorporated into the exhaust system
of an internal combustion engine.

Inside the reactor chamber 300 there is an inner
electrode 303 which is supported within a dielectric tube
10 304, made for example out of .-alumina which has its
upstream end closed by a spherical dome 305 to facilitate
the flow of exhaust gases through the reactor. The inner
electrode 303 is supported in the dielectric tube 304 by
two spider supports 306, 307. The inner surface of the
15 dielectric tube can be metallised with a metal coating in
order to increase the physical contact between the
electrode and dielectric tube. The support 307 is
connected to a high voltage input terminal 308 via a
ceramic insulated feed 309 so that a potential of the
20 order of kilovolts to tens of kilovolts and repetition
frequencies in the range 50 to 5000 Hz can be applied to
the inner electrode 303. Concentric with the inner
electrode 303 and dielectric tube 304 is a grounded outer
electrode 310 made for example of stainless steel. The
25 dielectric tube 304 and outer electrode 310 are supported
within the reactor chamber 300 by disks 311, 312 made of
an insulating ceramic material, such as alumina. A
compliant heat resistant material 313 is interposed
between the electrode support 311 and the dielectric tube
30 304.

The space between the dielectric tube 304 and the
outer electrode 310 is filled with a bed of active
material 320, shown in Figure 1, but omitted from Figure
35 2 for clarity of representation of the gas flow paths.

As shown in Figure 2, the outer electrode 310 has a
series of baffles 314 and slots 315 315a. The baffles
314 extend from the outer electrode 310 to the inner
surface of the wall of the reactor chamber 300 and act as
5   grounding connections as well as causing the exhaust
gases to follow a convoluted path which has both axial,
and circumferential components and being at least
partially helical. There is also a radial component of
flow, initially inwardly as the gas transfers from
10 outside the outer electrode 310 to the space between the
electrodes 310 and 303 and then outwardly as the gas
returns to exit from outside the outer electrode 310.
Thus there is also a spiral component in the flow.

15   The baffle 314 is arranged to divide the space
between the electrode 310 and the reactor chamber 300
into six segments. At the gas inlet end three of these
segments are closed off at 314a, 314b and 314c to axial
gas flow and the remaining three segments are open to
20 axial gas flow into the space between the electrode 310
and the reactor chamber 300. These latter three segments
are closed off by the baffle 314 at the gas outlet end of
the reactor. Consequently the gas is forced to pass via
slot 315 radially into the space between the electrodes
25 303 and 310 then passing in at least a partially helical
manner before passing radially via the next slot 315a
into the next segment of space between electrode 310 and
reactor chamber 300. The baffle 314 leaves open this
segment at the gas outlet end, allowing exhaust of the
30 treated gas. Thus it will be seen that the exhaust gases
both enter and leave the main part of the reactor 300
along the surface of the outer electrode 310 and the
electrode supports 311, 312 have reliefs at their
circumferences which are so positioned as to permit this
35 to happen. Thus for a given gas velocity, the residence
time of the exhaust gases in the electric field is

increased compared with either purely axial or radial
flow. Note that in Figure 2 part of the electrode 310 has
been shown cut away at 316. This cut away is shown in the
Figure only to illustrate the flow of the exhaust gases
5   as they pass between the electrodes 303 and 310 and does
not represent a structural feature of the reactor.

For a reactor suitable for the present invention
there may be adopted any other structural form as
10   described in our patent specification WO99/12638, or in
other embodiments described in the specification of our
patent application PCT/GB 00/01881. The active material
320 comprises polymeric, ceramic, or metallic material
which can be in the form of spheres, pellets, extrudates,
15   fibres, sheets, coils, granules, wafers, meshes, frits,
foams, honeycomb monolith or membrane in the plasma
region of the non-thermal plasma. Combinations of one or
more of the above can be used to create a structure with
a non-uniform surface area and porosity, for example a
20   graded porosity, when presented to the gas. Foams and
monoliths can be ceramic, metallic or polymeric and
examples of foams and monoliths include but are not
limited to alumina, zirconia, titania, zeolite for foams
and cordierite, silicon carbide, alumina, zeolite and
25   Fecralloy for a honeycomb monolith reactor. The active
material can also be a carbon combustion catalyst for
example cerium oxide, alkali metal oxide, or lanthanum
oxide/alkali metal oxide/vanadium pentoxide, vanadates
such as metavanadates and pyrovanadates. At least a
30   component of the active material 320 is selected or
modified in order to adsorb or trap a predetermined
chemical species in the gas flow thereby to increase the
effective residence time in the reactor of the said
species relative to the residence time of unadsorbed or
35   untrapped species in the gas flow. The active material
320 may comprise a plurality of components each of which

adsorbs or traps a different chemical species thereby to
increase the effective residence time in the reactor of
each of the different adsorbed or trapped chemical
species. It will be appreciated that a selected or
5 modified component of the active material may adsorb or
trap more than one selected chemical species. Also,
where a plurality of components is provided each of which
adsorbs or traps a different chemical species, the
respective adsorptions may be different for each
10 different adsorbed or trapped species, thus providing a
correspondingly different increase in the effective
residence time of each of the different adsorbed or
trapped species.

15   Suitable non-thermal plasma reactors are those of
the ferroelectric bed type comprising a bed of material
contained between two electrodes, dielectric barrier or
silent discharge type, pulsed corona discharge reactor or
surface discharge reactor or combination of reactors.

20

      When a gas molecule, for example, hydrocarbon enters
a non-thermal plasma it resides in the plasma zone for a
given period of time known as the residence time
whereupon chemical reactions can occur. When a selective
25 filter in accordance with the present invention is
present in the plasma region the residence time of
selected gas molecules in the plasma region increases.
This is because a selected gas molecule on entering the
plasma zone is adsorbed or trapped onto the surface of
30 material in the bed, and can then be activated, react and
desorb at a later time from the surface. The molecule
now in the gas phase can readsorb onto different regions
of the bed. This process of adsorption or trapping,
activation or reaction, desorption and readsorption can

occur throughout the plasma region thus increasing
residence times of selected molecules entering the plasma
region allowing chemical reactions to occur more
extensively. Controlled adsorption and desorption may be
5   used as an overall strategy to control the gas mixture
exiting the reactor. In another example the selective
filter may adsorb or trap species prior to plasma
activation and/or surface decomposition and subsequent
desorption. The material composition, e.g. acidity
10   (Bronsted and Lewis acid sites), pore size, pore shape,
pore size distribution, surface area are characteristics
which can be modified to effect different residence times
and selectivity.

15   The method of the invention is further illustrated
by considering the specific example of removing
carbonaceous particulate in the form of soot.

     Attention has been focussed in most prior art
20   arrangements on the removal of nitrogen oxides, without
consideration of soot removal, typically by passing the
gases containing the nitrogen oxides and soot for
treatment through a non-thermal plasma reactor which
contains no packing material (unpacked reactor), followed
25   by a suitable selective reduction catalyst. The role of
the plasma is to convert NO to NO_2 via a peroxy oxidation
chain mechanism. The initial steps of this mechanism are
believed to be dependant upon the reaction of O atoms,
formed by the plasma, with hydrocarbons which through a
30   chain mechanism (involving O_2 and OH reactions with the
hydrocarbons and products of the O and hydrocarbon
reactions) form peroxy species which are implicated in
the NO to NO_2 oxidation reaction. The NO_2 in the presence
of hydrocarbons in the exhaust gas is reduced to nitrogen

by the catalyst by a hydrocarbon selective catalytic
reduction mechanism.

　　　Removal of soot by non-thermal plasma oxidation as
5　it flows through an unpacked reactor would require a
relatively high energy input (joules per litre) achieved
by either applying a considerable increase in applied
energy or a considerable decrease in the exhaust gas flow
to an impractical level. Trapping the soot so as to
10　increase its residence time in the plasma reduces this
energy requirement. In the plasma region, the soot
becomes exposed to oxidative radicals such as O, OH, O_3
which then oxygenate the soot. The oxygenated soot has
different activated and catalytic properties to
15　unoxygenated soot, which result in, for example, its
oxidation at lower temperatures than would be observed
using a purely thermal technique. The material for the
selective filter for this purpose is primarily chosen for
its ability to trap soot. Beads of alumina (CT530)
20　provide a suitable material for this purpose, but may
desirably be combined with a combustion catalyst material
or a more soot-philic compound. Some improvement in the
trapping effectiveness of the material may be provided by
appropriate choice of the form in which the material is
25　incorporated in a reactor, that is specifically whether
it is incorporated in the form of sheets, wafers, meshes,
frits, coils, spheres, pellets, extrudate, granules,
fibres, foams or honeycomb monolith or as a coating on
sheets, wafers, meshes, frits, coils, spheres, pellets,
30　extrudates, granules, fibres or honeycomb monolith, foam,
or membrane.

　　　However, it is to be appreciated that using a
packing material to trap soot in this way results in
35　competition for the O-atoms and other oxidative species

which would otherwise be involved in the NO to NO_2 peroxy
oxidation chain mechanism. The rates of reaction of O
and other oxidative species with soot are faster than the
hydrocarbon oxidation reaction so that conversion of NO

5   to NO_2 is much less likely to occur.

      This is then an example of how using a selective
filter approach can significantly change the chemistry of
a system. In this example, a dominant homogeneous gas

10 phase reaction mechanism, plasma enhanced NO to NO_2
conversion is changed by the choice of a selective soot
filter to promote an alternative heterogeneous soot
oxidation mechanism using the same basic species found in
the exhaust stream.

15

      This has important implications for combined soot
and NO_x removal as this suggests that by removing the
soot in a packed reactor you reduce the possibility for
NO_x reduction to nitrogen by a hydrocarbon selective

20 catalytic reduction of NO_2.

      In accordance with the present invention, to achieve
a combined soot and NO_x removal this alteration in the
chemistry taking place within the reactor as a

25 consequence of trapping soot has to be taken into
account. One approach is to use an NO selective catalyst
such as a silver doped alumina catalyst, which functions
by selectively adsorbing both the NO and also
hydrocarbons and/or partially oxygenated hydrocarbons in

30 the exhaust and promoting their reaction together to
reduce NO directly to N_2. The function of this silver
doped alumina catalyst in this way is dependent upon the
type of hydrocarbons and its performance may be improved

by activation of hydrocarbons in the exhaust gas stream by for example plasma activation, to form species such as partially oxygenated hydrocarbons, for example formaldehyde (CH_2O). The presence of the non-thermal

5 plasma is important for this in that it is effective for the required activation of hydrocarbons at significantly lower temperatures than those required for thermal production of oxygenated hydrocarbons.

10 It will be apparent to those skilled in the art that this selective filter approach may be applied to other chemical processes, gases and exhaust streams.

The filter material may be selected for its ability

15 to trap or adsorb a predetermined species in the destruction of toxic waste compounds for example those used in applications such as the micro-electronics and semi-conductor industries. Examples of these include species such as volatile organic compounds, halogen-

20 containing compounds including perfluorocarbons, hydrofluorocarbons and Freons. Increasing the residence time of these species in the plasma by using a selective filter may result in an increase in the efficiency of their destruction.

25

In another example the selective filter material may be chosen for its ability to trap or adsorb a pre-determined species produced in the plasma to coat or modify the filter material in some way.

30

The filter material may be selected for its ability to trap or adsorb a predetermined species produced in the plasma to prevent a certain gas phase chemical reaction occurring. This could be to prevent a pollutant or toxin

35 being formed or to act as an inhibitor for a certain

isomer or molecule in a chemical process. As an example
the filter material may be selected for its ability to
trap or adsorb a predetermined polymer chain length or
type from the gas phase in a plasma polymerisation
5   process. The material could be selected to trap the
polymer products required or to take out unwanted by-
products to allow the desired product to be collected
downstream.

Claims

1.   A method of manufacturing a component for a non-
thermal plasma reactor (300) for the treatment of gases,
5   which method comprises assembling a bed of active
material (320) in an enclosure having gas flow conduits
(301,302) for directing gas to flow through or over the
bed of active material (320), providing electrodes
(303,310) adapted when electrically energised to generate
10 non-thermal plasma in the gas, characterised in that at
least a component of the active material is selected for
its capability to adsorb or trap a predetermined chemical
species in the gas flow thereby to increase the effective
residence time of said species relative to the residence
15 time of species in the gas flow which are not adsorbed or
trapped and so modify the gas phase and/or surface
chemistry of the treatment.

2.   A method as claimed in claim 1 for the treatment of
20 exhaust gases from an internal combustion engine, further
characterised in that the said active material (320) or
component thereof is selected for its capability to
adsorb or trap a predetermined chemical species in the
exhaust gas flow produced as a result of the combustion
25 of fuel, and any modifier or additive therein, by the
internal combustion engine.

3.   A method as claimed in claim 1 or claim 2, further
characterised in that the said active material (320) or
30 component thereof is selected for its capability to
adsorb or trap a predetermined chemical species in the
gas flow produced by non-thermal plasma activation of
constituents thereof.

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4.   A method as claimed in claim 2 or claim 3, further characterised in that the predetermined chemical species is from the group comprising nitrogen, oxygen, oxides of nitrogen such as NO, NO_2, oxides of carbon such as CO,

5   CO_2, water, hydrocarbons including saturated, unsaturated, cyclic, branched and un-branched hydrocarbons, oxygenated hydrocarbons such as aldehydes, ketones, alcohols, acids ethers and esters, aromatic hydrocarbons and derivatives thereof including poly

10   aromatic hydrocarbon compounds, oil fractions, fuel and partially burned fuel, air and air/fuel mixes, smoke, carbonaceous particulate including the soluble organic fraction and carbon, fine and ultrafine fraction, sulphur compounds including SO_2 and sulphates, organo-nitrogen

15   species, acid gases, combustion modifiers/enhancers, additives such as urea, ammonia, cerium oxide (such as Eolys) and plasma activated species such as O, OH, O_3 activated hydrocarbons including partially oxygenated hydrocarbons/organic molecules and electronically and

20   vibrationally excited state species.

5.   A method as claimed in any of the preceding claims, further characterised in that the bed of active material (320) is provided in the form of sheets, wafers, meshes,

25   frits, coils, spheres, pellets, extrudate, granules, fibres, foams or honeycomb monolith or as a coating on sheets, wafers, meshes, frits, coils, spheres, pellets, extrudates, granules, fibres or honeycomb monolith, foam, or membrane.

30

6.   A method as claimed in any of the preceding claims, further characterised in that the active material (320) comprises dielectric or ferroelectric material.

7.   A method as claimed in any of claims 1 to 5, further
characterised in that the active material comprises
polymeric material.

5   8.   A method as claimed in any of claims 1 to 5, further
characterised in that the active material comprises
ceramic material.

9.   A method as claimed in any of the preceding claims,
10 further characterised in that dielectric barrier material
(304) between the electrodes (303,310) establishes a
dielectric barrier discharge type of reactor.

10.   A method as claimed in any of claims 1 to 8, further
15 characterised in that the electrodes are configured to
provide a pulsed corona discharge type of reactor.

11.   A method as claimed in any of claims 1 to 8, further
characterised in that the electrodes are configured to
20 provide a surface discharge type of reactor.

12.   A method as claimed in any of the preceding claims,
further characterised in that the electrodes (303,310)
are configured to generate plasma in the gas as it flows
25 over or through the bed of active material (320).

13.   A non-thermal plasma reactor for the treatment of
gases when made by a method as claimed in any of the
preceding claims.

30

14.   A non-thermal plasma reactor for the treatment of

gases, comprising a bed of active material (320) in an enclosure having gas flow conduits (301,302) for directing gas to flow through or over the bed of active material (320), electrodes (303,310) adapted when

5   electrically energised to generate non-thermal plasma in the gas, characterised in that at least a component of the active material (320) is modified so as to adsorb or trap a predetermined chemical species in the gas flow to increase the effective residence time of the said species

10   relative to the residence time of species in the gas flow which are not adsorbed or trapped and so modify the gas phase and/or surface chemistry of the treatment.

15. A non-thermal plasma reactor as claimed in claim 14,
15   further characterised in that neither the plasma nor the said modified component is separately catalytic with respect to reactions of chemical species in the gas, but by virtue of the combined effect of the plasma and the adsorption or entrapment a catalytic effect on reactions

20   is achieved.

16. A non-thermal plasma reactor as claimed in claim 14 or claim 15, further characterised in that the bed of active material (320) includes one or more catalysts from

25   the group comprising alkali metal-exchanged zeolite Y or silver aluminate and other metal-exchanged or metal doped zeolite material including Cu/ZSM-5, Fe/ZSM-5, Co/ZSM-5, zeolite beta and hydrogen exchanged zeolites including H-ZSM-5, or the group comprising aluminas including alpha,

30   gamma, chi and other crystalline phases, oxides of titanium, zirconium, cerium and vanadium, perovskites, spinels and mixtures of these materials, or metal doped inorganic oxides such as cobalt-doped aluminas.

35   17. A non-thermal plasma reactor as claimed in claim 16,

further characterised in that the bed of active material
(320) includes a carbon combustion catalyst comprising
one or more materials from the group comprising alkali
metal oxide, or lanthanum oxide/alkali metal

5   oxide/vanadium pentoxide, vanadates such as metavanadates
and pyrovanadates

18.   A non-thermal plasma reactor as claimed in claim 14
or claim 15 or claim 16 or claim 17, further

10 characterised in that means are provided for controlling
release of an adsorbed or trapped species.

19.   A non-thermal plasma reactor as claimed in claim 18,
further characterised in that the said means for

15 controlling release of an adsorbed or trapped species
comprises means for controlling the temperature of the
modified component.

20.   A non-thermal plasma reactor as claimed in any of

20 claims 14 to 19, further characterised in that the said
predetermined chemical species is carbonaceous soot, and
desorption and/or decomposition of carbon functionalities
formed therefrom and resultant production of carbon
dioxide and carbon monoxide occurs at temperatures lower

25 than the thermal oxidation temperature of carbonaceous
soot.

21.   A non-thermal plasma reactor as claimed in claim 20,
further characterised in that the said resultant

30 production of carbon dioxide and carbon monoxide occurs
at temperatures lower than 250°C.

22.   A non-thermal plasma reactor as claimed in claim 20,
further characterised in that the said resultant

35 production of carbon dioxide and carbon monoxide occurs
at temperatures as low as 100°C.

1/1
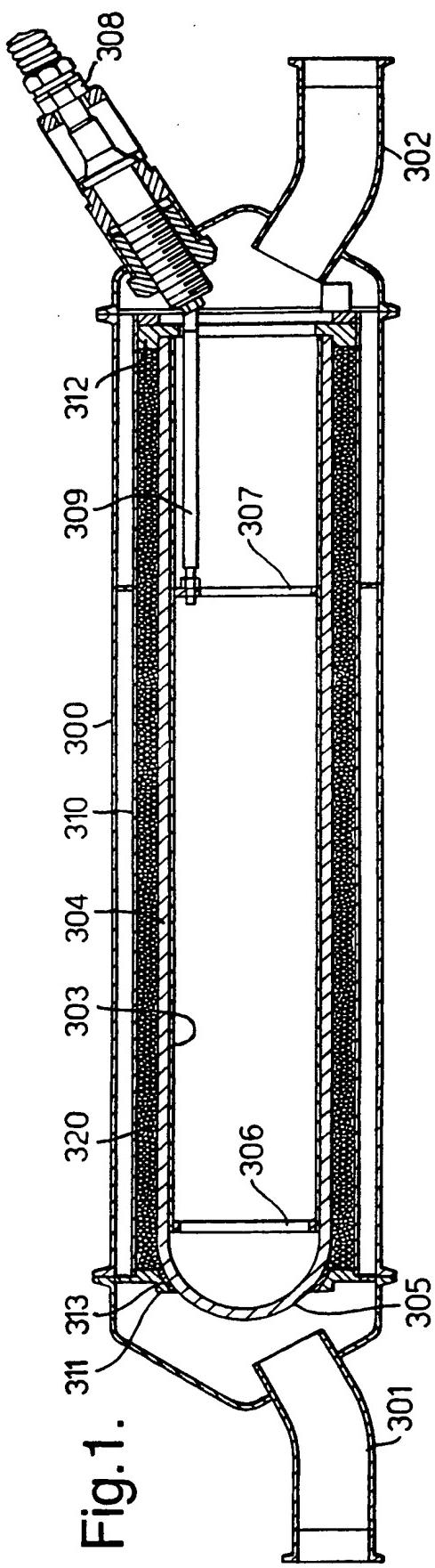
Fig.1.
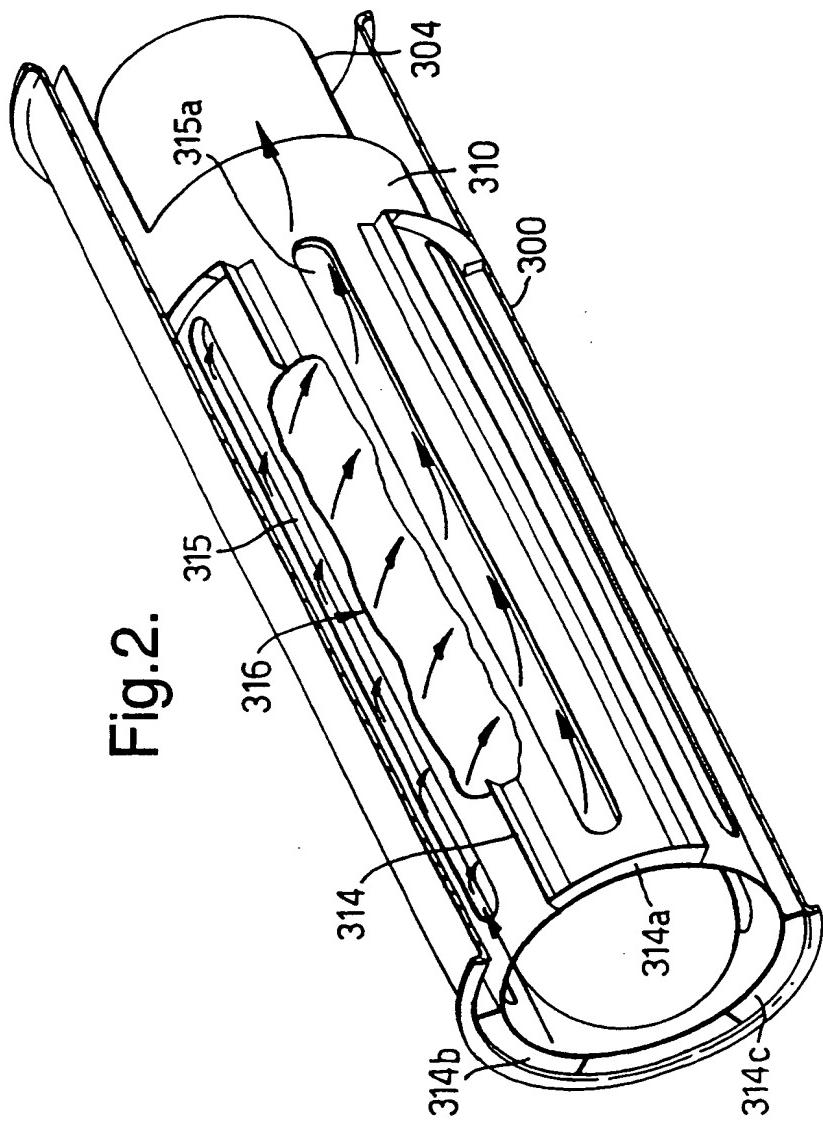
Fig.2.

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   B01D53/32   F01N3/08   F01N3/01   F01N3/027

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   F01N B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and. where practical, search terms used)

WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 746 984 A (HOARD JOHN W) 5 May 1998 (1998-05-05) column 5, line 53 –column 8, line 61; figures 1-4 ---	1-6, 8-16,18, 19
X	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 09, 30 July 1999 (1999-07-30) & JP 11 114351 A (SANDENSHA:KK;YAMAMOTO TOSHIAKI; YOU SADAYOSHI), 27 April 1999 (1999-04-27) abstract ---	1,13,14, 18
A	US 5 715 677 A (VOGTLIN GEORGE E ET AL) 10 February 1998 (1998-02-10) abstract; figures --- -/--	1,14, 20-22

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 January 2001	15/01/2001

Name and mailing address of the ISA European Patent Office. P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040. Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Sideris, M

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document. with indication.where appropriate. of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 09, 30 July 1999 (1999-07-30) & JP 11 114359 A (AGENCY OF IND SCIENCE &TECHNOL), 27 April 1999 (1999-04-27) abstract —————	

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JP 11114351	A	27-04-1999	NONE		
US 5715677	A	10-02-1998	NONE		
JP 11114359	A	27-04-1999	NONE		